INCLUSIVE PHOTON PRODUCTION IN HADRONIC COLLISIONS

M. WERLEN
Laboratoire d'Annecy-le-Vieux de Physique Théorique LAPTH,
F-74941 Annecy-le-Vieux, France
and EP division, CERN, CH-1211 Geneva 23

High statistics fixed target and ISR inclusive photon production data are compared to next-to-leading order (NLO) QCD calculations. The dependence of the theoretical predictions on the structure functions, and on the theoretical scales is investigated. It is shown that the data cannot be simultaneously fitted with a single set of structure functions and scales. However, it is argued that as long as one restricts the data/theory comparison to the x_T range where the theory is reliable, i.e. stable with respect to the scale variation, there is no need to introduce an additional primordial k_T dependence except for Be data. Finally a precise determination of the strong coupling constant, α_s, is performed from the direct photon production cross sections obtained in high statistics $\bar{p}p$ and pp collisions at the CERN SPS (UA6) by a NLO QCD analysis.

1 Critical study of photon production in pp and pBe interactions

Inclusive photon production including the direct and the bremsstrahlung contributions, calculated at NLO in QCD [1], is compared to experimental data in the range $\sqrt{s}$=23 GeV to 63 GeV as a function of $x_T = 2p_T/\sqrt{s}$. The following experimental data are used: the pp data from WA70[2] and from ISR R806[3], R110[4], AFS[5] and R108[6] as well as the new fixed target data from E706 [7] (pBe) and UA6 [8] (pp and $p\bar{p}$). The main results of this study are summarized below. They concern the theoretical prediction uncertainty and possible incompatibilities between data sets.

The perturbative NLO calculations involve three arbitrary scales: the factorization scale M, the renormalization scale μ and the fragmentation scale M_F. As those scales are unphysical, the theory can be considered reliable only in the region of the phase space where the predictions are stable with respect to the scale variations. For a large range of M_F values, the theory stability versus M and μ is reasonable for $x_T > .35$ at $\sqrt{s}$=23 GeV, $x_T > .32$ at $\sqrt{s}$=31.6 GeV, $x_T > .26$ at $\sqrt{s}$=38.8 GeV and $x_T > .16$ at $\sqrt{s}$=63 GeV. The theoretical uncertainty due to the scales is approximated by the difference in the predictions between $M = \mu = M_F = p_T/3$ and $M = \mu = M_F = p_T/2$.

The ratio data/theory is shown in Fig. 1 with all scales set to $p_T/2$ and using the parton distribution functions CTEQ4M [9]. A large discrepancy can be seen between the E706 and the other data sets. Although there is an approximate agreement with theory for the WA70, UA6 and ISR data sets, the E706 data are underestimated by the theory by a factor 2 in the region of theory stability and up to 4 at low x_T. In Fig. 2 the same experimental data are compared with the theory with all scales set to $p_T/3$ and using the parton distribution functions MRS98-2 [10]. Here too the theory underestimates the E706 data by 50% in the region of theory stability and by up to 100% at low x_T.

Clearly, the full set of available data cannot be fitted by the theory whatever the scales or the structure functions. Restricting the comparison to the x_T range of theory stability reduces the discrepancy to a mere global scaling of the E706 data.

It has been proposed to introduce a parton-k_T broadening effect [7,11] to account for the low x_T dependence and for the scaling effect seen by E706. This effect would destroy the theoretical agreement of all other experiments particularly in x_T region of theory stability.

A NLO QCD calculation has been performed for π^0 production [12]. Setting all scales to $p_T/2$, the low x_T rise observed in the direct photon case (Fig. 1) has almost disappeared (Fig.3). Moreover, when all scales are set to $p_T/3$, a common rescaling of the theory by a factor 1.5 ± 0.2 is enough to accommodate all fixed target data. This normalization may not be unrealistic as the absolute normalization of the theory is not precise, due for example to present uncertainties in the π fragmentation. The fixed target π^0 data appear in better agreement then the photon data.

2 Determination of α_s from UA6 data [13]

The measurement in the same experiment of the production of direct photon in pp and $\bar{p}p$ collisions [8] allows a clean isolation of the annihilation process ($q\bar{q} \to \gamma g$) from the difference $\sigma(\bar{p}p \to \gamma X) - \sigma(pp \to \gamma X)$. Knowing the quark distributions, this process provides a direct handle on $\Lambda^{(4)}_{\overline{MS}}$ and therefore α_s. Quark distributions vs $\Lambda^{(4)}_{\overline{MS}}$ have been obtained from fits to BCDMS [14] deep inelastic scattering data. Therefore $\Lambda^{(4)}_{\overline{MS}}$ remains the only free parameter in the fit of the UA6 data to the NLO theoretical calculations. The results are shown in Fig. 4 for various choices of scales.

For optimized scales [15], the best χ^2 gives $\Lambda^{(4)}_{\overline{MS}}$ of $210 \pm 22\,(stat.) \pm 44\,(syst.)$ MeV. We conservatively assign an overall theoretical uncertainty of $^{+105}_{-36}$ MeV, dominated by uncertainty in the μ and M scale selection.

This leads to $\alpha_s(M_Z^2) = 0.1112 \ \pm 0.0016\,(stat.) \ \pm 0.0033\,(syst.) \ ^{+0.0077}_{-0.0034}\,(theo.)$ in good agreement with the world average value [16] and with error bars comparable to those achieved in deep inelastic scattering [17,18]. Recent improved NLO computation for $\bar{p}p$ including resummation shows small corrections for small scales as used here and furthermore reduces the scale dependence as expected [19]. Hence these new calculations should not change significantly the α_s value.

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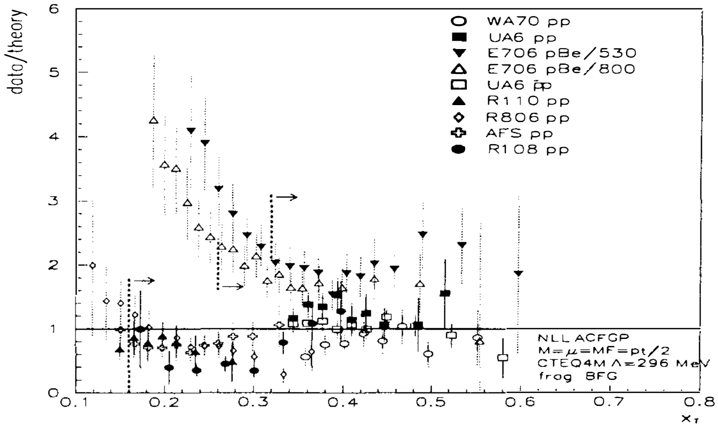

Figure 1: Ratio data/theory for direct photon production using CTEQ4M distribution functions. All scales are set to $p_T/2$. The arrows note the x_T ranges where the perturbative predictions are reasonably stable vs variation of the scales μ and M. Statistical errors are shown as full lines, statistical and systematic errors added in quadrature are shown as dashed lines.

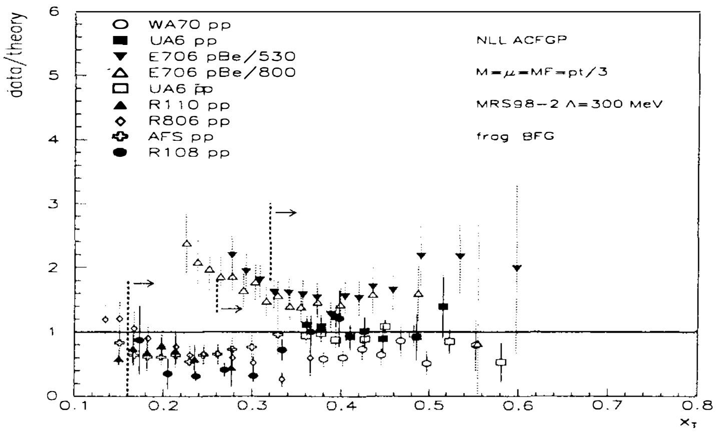

Figure 2: Ratio data/theory for direct photon production using MRS98-2 distribution functions. All scales are $p_T/3$.

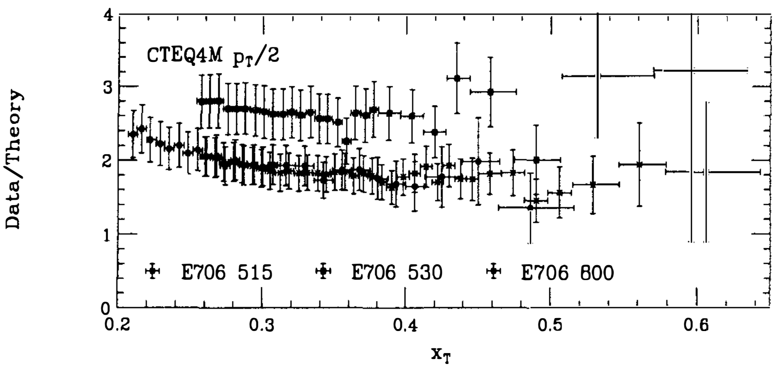

Figure 3: Ratio data/theory for π^0 production using CTEQ4M parton distribution functions. All scales are set to $p_T/2$. The E706 pBe data with beams of 530 GeV/c and 800 GeV/c as well as the E706 π^-Be data with a beam of 515 GeV/c (not discussed here) are shown.

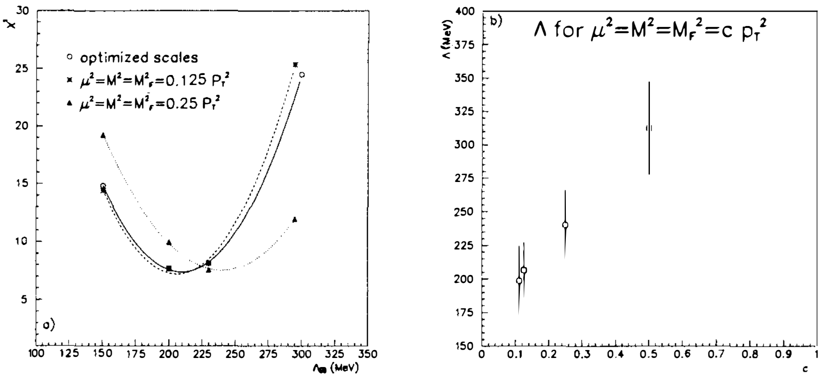

Figure 4: a) The χ^2 between the theoretical predictions and the measured cross section difference $\frac{d\sigma(\bar{p}p\to\gamma X)}{dp_{Ti}} - \frac{d\sigma(pp\to\gamma X)}{dp_{Ti}}$ summed over ten p_{Ti} bins as a function of $\Lambda^{(4)}_{\overline{MS}}$ for various choices of scales. b) Best value of $\Lambda^{(4)}_{\overline{MS}}$ as a function of the parameter c defining the scales $\mu^2 = M^2 = M_F^2 = cp_T^2$. The error bars are statistical only.